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A MODIFIED RAIL SHEAR TEST
FOR THIN COMPOSITE PLATES

A THESIS

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A MODIFIED RAIL SHEAR TEST

FOR THIN COMPOSITE PLATES

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SUMMARY

The stimulus of this investigation was provided by the need for a standard test to measure shear strength and shear modulus of composite materials. Because of its simplicity in both design and experimental procedure, the rail shear test afforded an excellent starting point. This method, however, has certain limitations and it is the objective of this study to eliminate some of them and produce a more dependable and useful test for shear properties.

The first step is to change the rail fixture to permit tensile loading instead of the conventional compressive loading. In addition, the fixture features self-adjusting pin joints to prevent out-of-the-plane loading in the specimen and stepped-down clamping rails to assure more even load transmission to the specimen. All of these features help to reduce the possibility of buckling failure modes - a failure that seems to have occurred with the traditional rail shear test.

A series of tests were performed using boron filament composite specimens of three major types - 0/90, ± 30, 0/± 60 laminates. The specimens were tested for in-plane shear strength and shear modulus. In each major group of specimens both symmetric and anti-symmetric stacking sequence were tested. The modulus values were obtained using three-arm

strain gage rosettes mounted in the center of the test area.

As a criteria for judging the test, the experimental shear strength and modulus values are compared to values predicted by a computer laminate analysis program. The shear modulus obtained from the test compare quite favorably to the predicted results and the shear strength values are lower than the predicted values but higher than those obtained from other tests. The modes of failure seem to be either shear failure or delamination with shear failure, with each group of specimens appearing to have a definite type of failure mode.

CHAPTER I

INTRODUCTION

Shear Testing

The use of lightweight composite materials as a structural material is an expanding field; however, the use of such materials depends on the designer's ability to find an accurate strength value for the given materials.

The area of intralaminar shear properties has presented the greatest problems to the designer, since the tests used to obtain in-plane shear properties are the most varied and least standardized. The primary difficulty is in inducing a state of pure shear (no normal or secondary stresses) on the specimen.

The most direct method of applying the state of pure shear is by applying a pure torque to a tubular specimen (1,2,3). The one advantage of this method is greatly outweighed by a multitude of disadvantages; the problems of fabrication and induced stresses in bending the filaments are enough to make this method inadvisable.

The difficulties of fabrication of composite materials point the way to developing a suitable shear test using plate or coupon specimens.

Several types of tests using plates or coupons have been tried. One test is to put 0, 90, and 45 degree oriented coupons in pure tension and reduce the data to find the shear properties (4,5). This method gives consistent results but its "backdoor" approach leaves the test results open to suspicion.

A second method is the deformation of a plate into a saddle configuration (5,6). This method is limited because no strength values are obtained, only shear modulus values. This method, however, can be used as a check for other test values of shear modulus.

A third type of test, taken from metal testing, is the "picture-frame" test (7,8). This consists of a square plate loaded by four pairs of pinned (or free) rails. The corners are loaded so as to distort the square into a diamond shape. The disadvantages in this test are again numerous. A general stability problem occurs with buckling failures occurring early. Also a restoring moment of unknown magnitude may be present at the rails.

Finally, the aerospace industry has introduced the rail shear test which uses a flat, rectangular plate specimen (9). This test consists of two pairs of rails clamped or bonded to the long sides of the rectangular specimen; the two short sides remain free. The shear stress is then induced by the relative displacement of one rail to the other. This displacement has been generally caused by placing the rails in a compressive mode.

At first glance, the rail shear test appears as the least likely possibility for the standard test for shear properties. The two free edges of the specimen definitely show that the specimen is not in a state of pure shear. This obvious inconsistency is negated by Coker's photoelastic work (10) and by a finite element analysis by Sethi (11), both of which indicate that a state of pure shear does exist at a short distance from the free edge for large length-to-width ratios. The boundary conditions at the two rails may produce unknown stresses; however, at this time Sethi's work indicates no great variation from pure shear in the center of the specimen. As Whitney (12) points out, this test is very promising from a practical standpoint. The test method is simple, inexpensive, and adaptable to various test temperatures.

The promising features of the rail shear test prompted the design of a modified rail shear test to be used as a standard for testing filament composite materials.

Design of Modified Rail Shear Test

The design of a modification of the existing rail shear test was limited by certain material conditions. The available specimens were already fabricated in the configuration prescribed by the conventional rail shear test. Figure 1 shows the detail of these specimens. They conform to the necessary length to width ratios as prescribed by Coker (10),

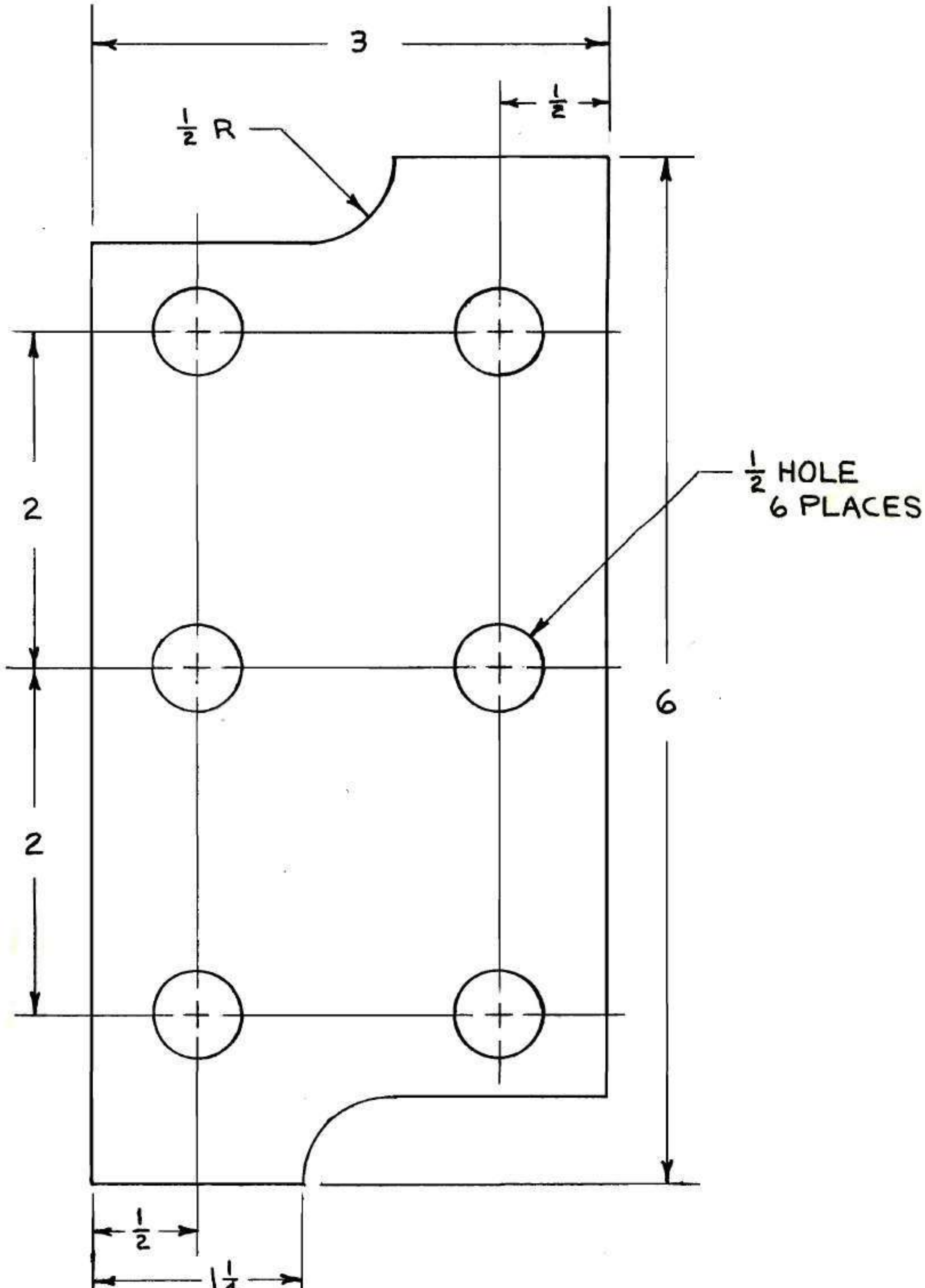

Figure 1. Rail Shear Test Specimen

Boller (9), and Whitney (12). The specimens are, however, not in accordance with prescribed thickness values of Boller (9,13). His requirement of thickness values of 1/16 to 1/8 inches is due in part to the stability problems inherent in the test.

This buckling problem prompted the first major modification of the existing rail shear test. Instead of performing the test in a compressive mode, the rails would be relatively displaced under a tensile load. As Figure 2 illustrates, this greatly decreased the specimen length under compression and therefore increased the stability of the test area.

A second modification of the fixture also dealt in part with the stability problem. The rails were fastened to an external frame which prevented any distortion around the y-axis. This modification was used in lieu of Stoll's (14) guide rails.

Another factor which influenced the design of the fixture was the problem of allowing the test area to decrease in width as the shear increased. If the width was constrained to a constant value, the state of pure shear deformation, as shown in Figure 3, could not be achieved.

This problem was solved by pinning the rails in the x-y plane. This also led to the addition of a pin joint in the y-z plane for freedom from any normal loads in this plane.

With these modifications some of the shortcomings of

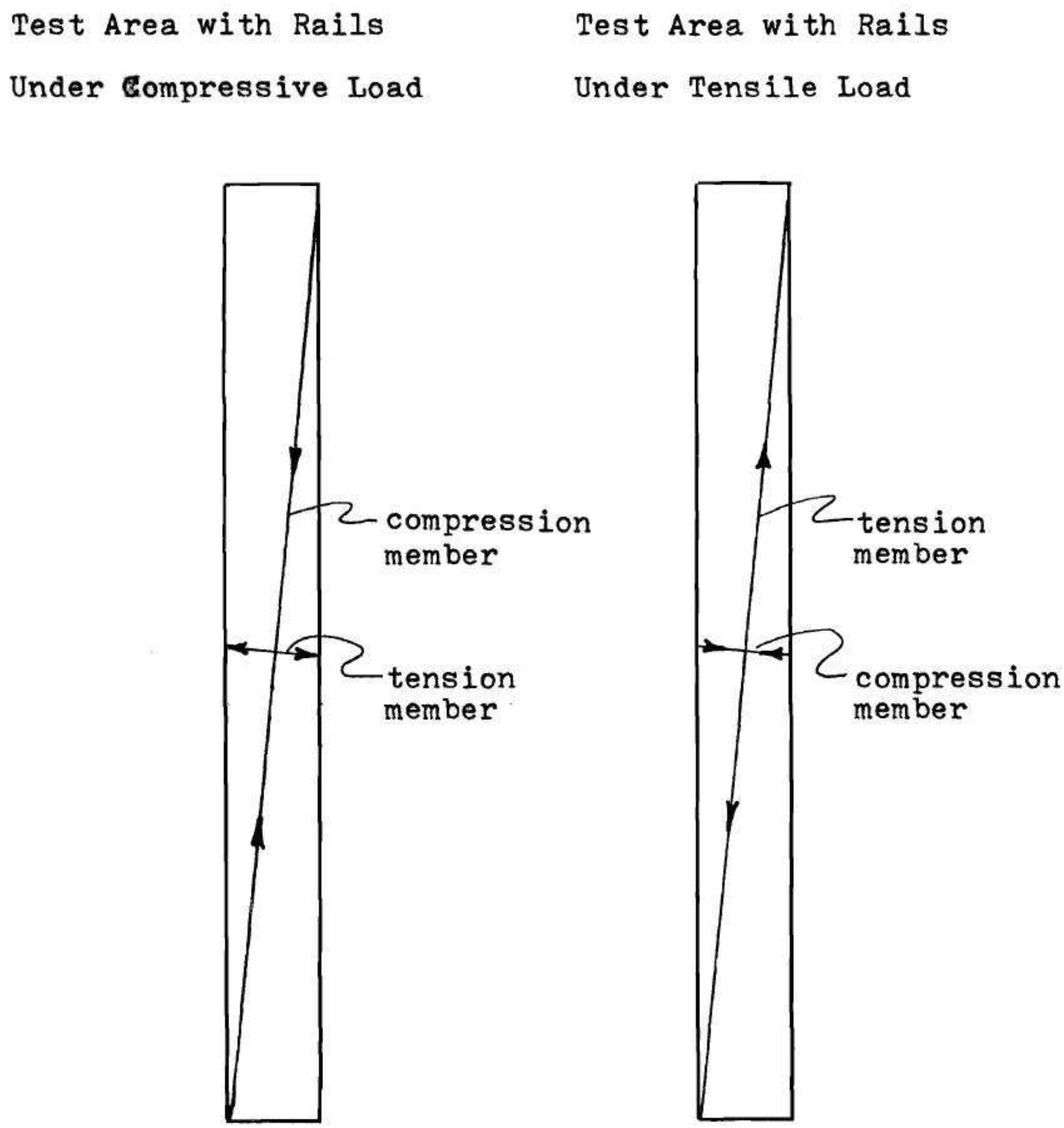

Figure 2. Comparison of Compression versus Tension Loading

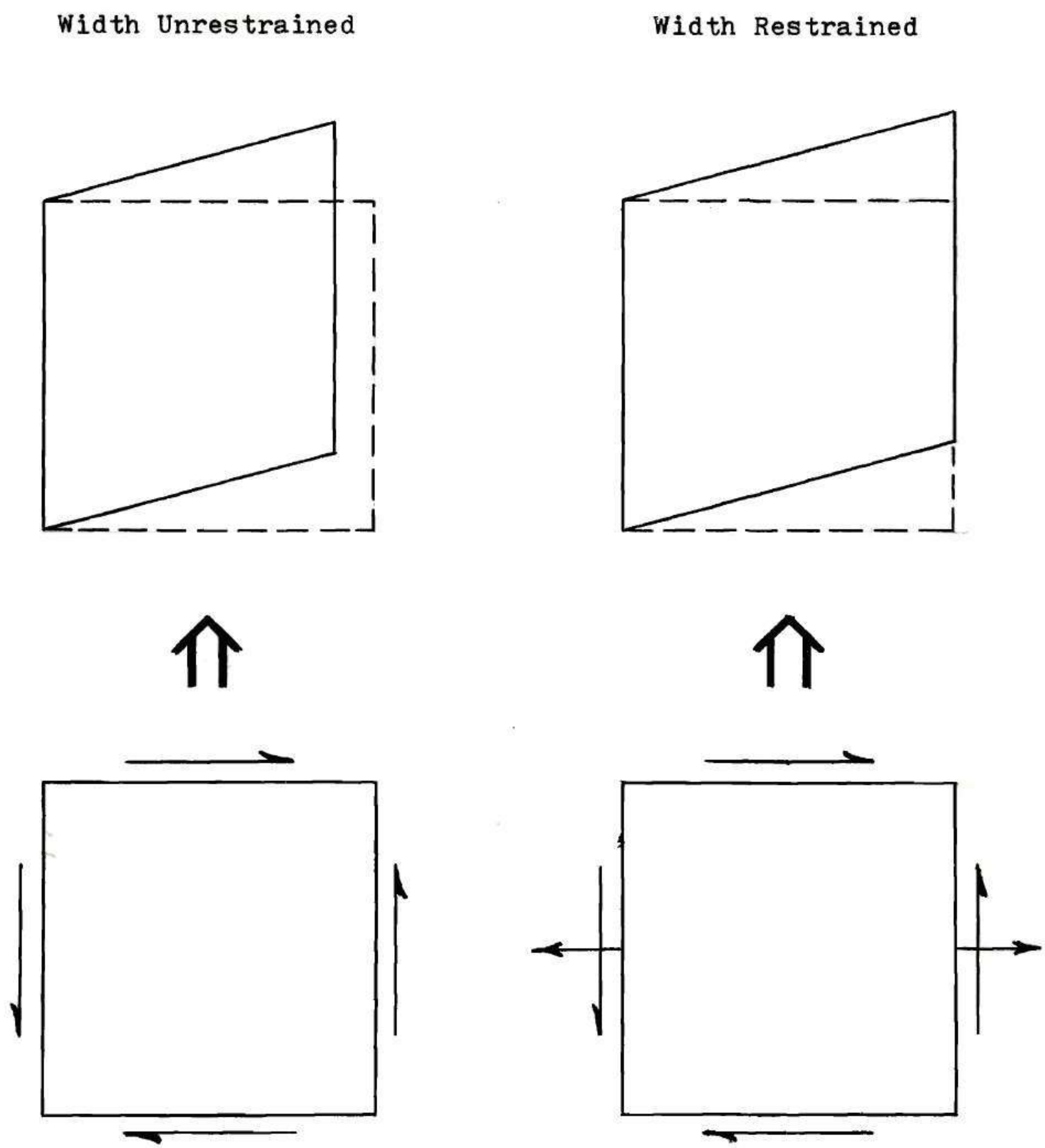

Figure 3. Loading to Obtain Pure Shear

the conventional rail shear test were hopefully overcome.

Test Performed

After fabrication of the modified rail shear test, its worth could only be ascertained by test data obtained from using the fixture.

The test specimens were divided into three major groups based on filament orientatations. Each major group was then divided into two groups - symmetric lay-up and anti-symmetric lay-up.

The first group consisted of four ply specimens of zero and 90 degree filament orientation. This group was designated group 1 with 1A representing the symmetric (0/90/90/0) stacking sequence and 1B signifying the anti-symmetric (0/90/0/90) lay-up. There were eight specimens in both groups 1A and 1B and each specimen was assigned a number, i.e. 1A-1, 1A-2, 1A-3. Two of the eight specimens were tested with strain gages mounted on the center of the test area. The remaining three specimens were tested with no instrumentation. All tests were carried to failure of the specimen.

Group 2 consisted of four ply specimens also, but the filament orientation was ± 30 degrees. The same nomenclature format was used with 2A being +30/-30/-30/+30 lay-up and 2B being the anti-symmetric +30/-30/+30/-30 stacking sequence. Group 3 specimens were six ply thick with the filaments oriented in 0/+60/-60/-60/+60/0 for the 3A type and 0/+60/-60/

+60/-60/0 configuration for the 3B type.

In group 2 and group 3 the same numbering was used as in group 1, and five specimens of each type of lay-up were strain gaged with the remaining three specimens not instrumented.

CHAPTER II

INSTRUMENTATION AND EQUIPMENT

Instron Description

All tests were performed on an Instron Universal Testing Instrument Model TT-D-L. This machine incorporates a highly sensitive electronic weighing system with load cells that use strain gages for detecting and recording tensile or compressive loads. The moving crosshead is operated by two vertical, low speed drive screws. A positional servomechanism maintains accuracy and alignment control over the crosshead motion. The chart of the recorder is driven synchronously at chosen speed ratios (with respect to the crosshead), enabling measurements of sample deformation to be made with varying magnifications.

The load cell used had a maximum full scale sensitivity of 0 - 20,000 pounds. This load cell is a tension or compression cell and can record loads under either type (tension or compression) loading, depending on the test set-up and location of the cell. The load cell incorporates bonded strain gages mounted within the cell housing on a strain sensitive simple tension member. The internal member is supported by means of diaphragms, eliminating response to nonaxial loading. Positive stops within the housing protect the internal member from accidental overloading and the resultant (possibly unknown) damage to the gages. The strain gages in the load cell operate similarly to the strain gages used for test investigations. An applied load on the cell causes a proportional change in the resistance of the strain gages mounted on the calibrated internal tension member. The gages are arranged in a Wheatstone-bridge circuit. The resulting signal is amplified, rectified to d.c., and fed to the pen driving circuit of a high speed potentiometer recorder. Within the amplifier circuit are means to compensate for the weight of the test fixture and the samples themselves. The sensitivity of the amplifier may be changed in calibrated steps of full range ratios of 10, 20, 50, 100, 200. The accuracy of the load weighing system is ± 0.5 per cent of the recorder scale in use, whichever is greater.

The crosshead operates on a constant strain rate and loads a specimen through vertical drive screws which produce a constant straining of the specimen regardless of load response. The crosshead speed can be varied at any time during the test by means of fast response electro-magnet clutches operated by pushbuttons which provide seven standard speeds. This feature was not used since a rate of 0.05 inches per minute was used throughout the tests.

The recording system incorporates a potentiometer driven pen arm, described earlier as an output medium for the load weighing system, and a means to drive the chart on an orthogonal axis to the load axis. A synchronous motor with various change gears drives the chart at a constant speed. Because of their synchronous operation, there is a correspondence between the individual motions of the chart and crosshead. This close relationship is maintained by virtue of the low inherent deflection of the load cells and the almost total elimination of backlash in the crosshead drive assembly. However, since the chart is not coupled directly to the crosshead, the chart drive direction can be considered a time axis.

Strain Measurements

Strain measurements were made using strain gages bonded to the center of the test section. A three arm (45 degree) epoxy-backed foil rosette, model BLH PFAER-12R-12-L, was mounted in the center of the test area. The gage was a 120 ohm resistor type with factory installed lead wires. Mounting was accomplished using Eastman 910 acrylic adhesive. This is a pressure sensitive, quick drying adhesive which is quickly applied. Since adequate bonding is affected by humidity conditions, the gaged specimen should be tested within a period of two weeks from application of the strain gage.

The strain readings were made using a Budd Digital Strain Indicator. This indicator operates on either a half bridge or whole bridge (Wheatstone) circuit. The half bridge circuit was used with a temperature compensation gage placed in a circuit for correction in output due to temperature variance. The indicator also requires the gage factor to be set before balancing the circuit. Output is displayed on a digital counter in micro inches per inch. The strain gage leads were attached to a Budd Switching and Balancing Unit which was in turn connected to the strain indicating unit. The switching and balancing unit could accommodate 10 strain input leads. Each strain gage arm input lead was connected to the unit and balanced manually. The balancing unit does not rebalance the bridge circuit as the load is applied. The error this produces is considered minimal.

Modified Rail Shear Fixture

A special modified rail shear fixture was designed and fabricated to perform the tests.

As seen in Figure 4, the major structural feature is an outer frame made of one inch aluminum plate on the top and bottom and two one inch diameter stainless steel rods. The two rods are clamped rigidly in the lower plate and slide through two Thompson linear bearings which are affixed to the upper plate. This outer frame provides rigidity and support for the whole fixture.

In the center of each of the frame plates are the rail attachments. This mechanism consists of two pin joints which allow rotation in the x and z direction to assure a state of pure shear on the specimen.

The rails are attached to the second pin joint. They

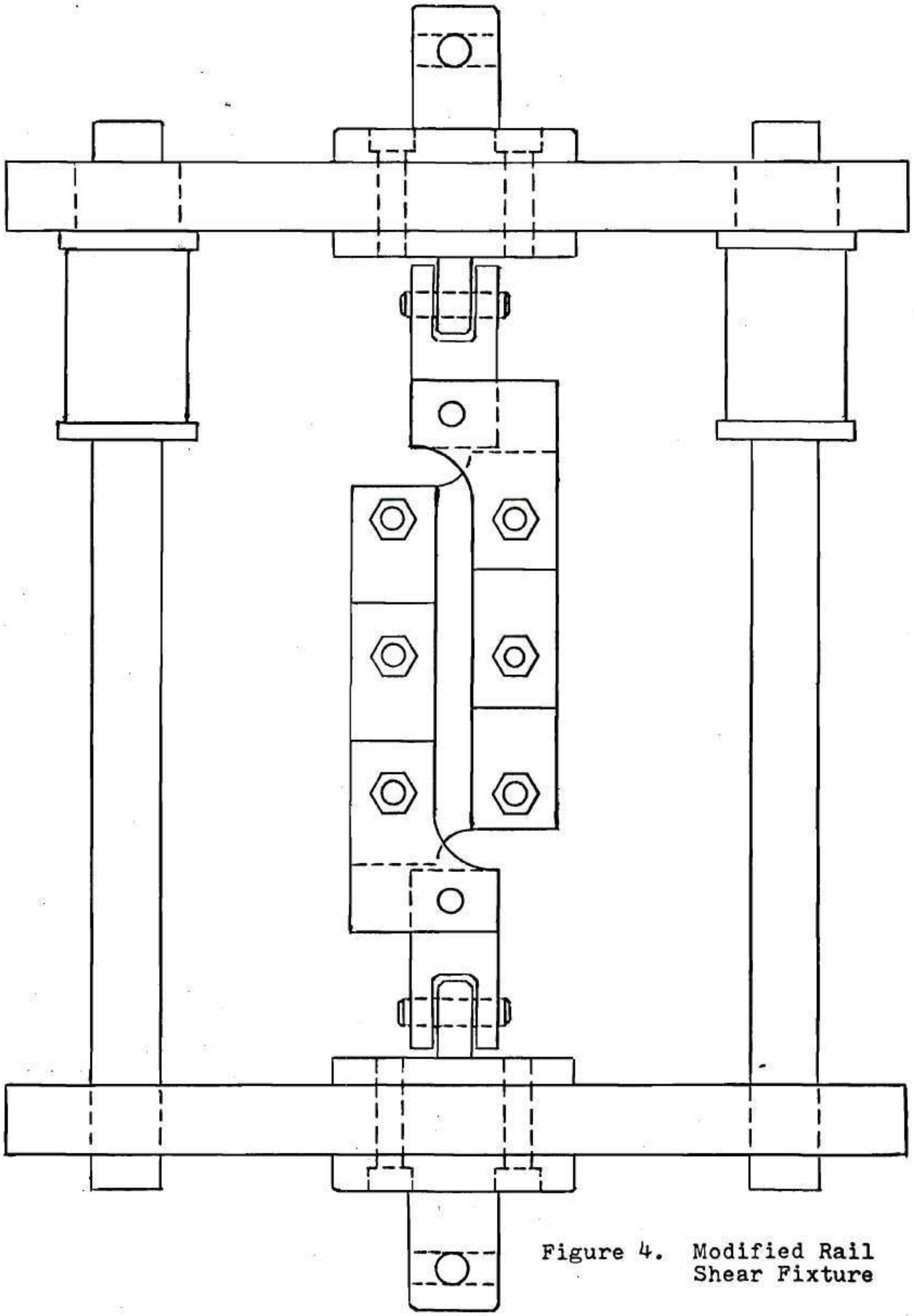

Figure 4. Modified Rail
Shear Fixture

are installed by slipping each rail and its mate on the pin. Bushings are press fitted in the rails to provide a bearing surface and minimize friction in the pin joint. Figure 5 shows how each rail is stepped in an approximation to transfer the load evenly along the edge of the specimen.

The specimen is clamped along its long sides by the pairs of rails. The rails are clamped to the specimen using six 3/8 inch diameter high shear strength bolts - three through each pair of rails.

The whole fixture is mounted in the Instron machine by two male fittings located in the center of the frame plates. These fittings mate with existing Instron fixtures and are secured by high strength shear pins, 1/2 inch in diameter. The Instron is then operated in a tensile mode and shear is applied to the specimen by the relative displacement of the pairs of rails to each other.

The entire apparatus can easily be installed or removed in a matter of minutes and is light enough for one person to handle.

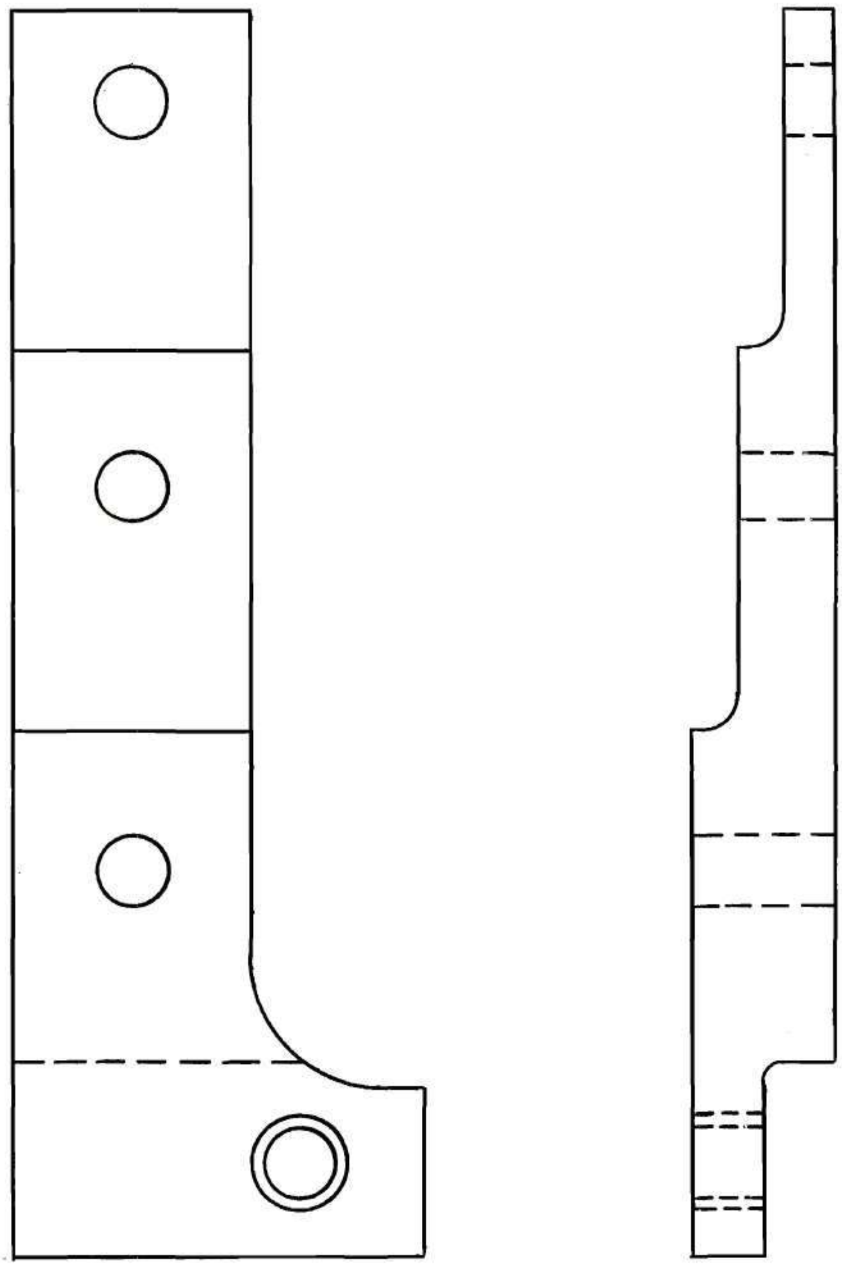

Figure 5. Detail of Clamping Rails

CHAPTER III

EXPERIMENTAL PROCEDURE

The procedure used in conducting this modified rail shear test was the same for each type of specimen. No special techniques were found to be necessary for different specimen lay-ups.

The specimens of each type were examined and five typical specimens of each configuration were chosen for strain gage application. The remaining specimens were tested without instrumentation for strain readings.

The procedure for strain gage installation was a simple one. The specimen was cleaned using isopropyl alcohol and the center of the test area marked. The gage was positioned in the center of the test area in the orientation shown in Figure 6, and bonded to the specimen using Eastman 910 acrylic cement. Each group of three to four specimens was tested within the week that the strain gages were applied because of the time limitations imposed by the use of Eastman 910.

After strain gages were applied, the specimen was mounted in the rail shear fixture using a definite procedure. The first and undoubtedly the most important problem in mounting the specimen was insuring that maximum clearance between

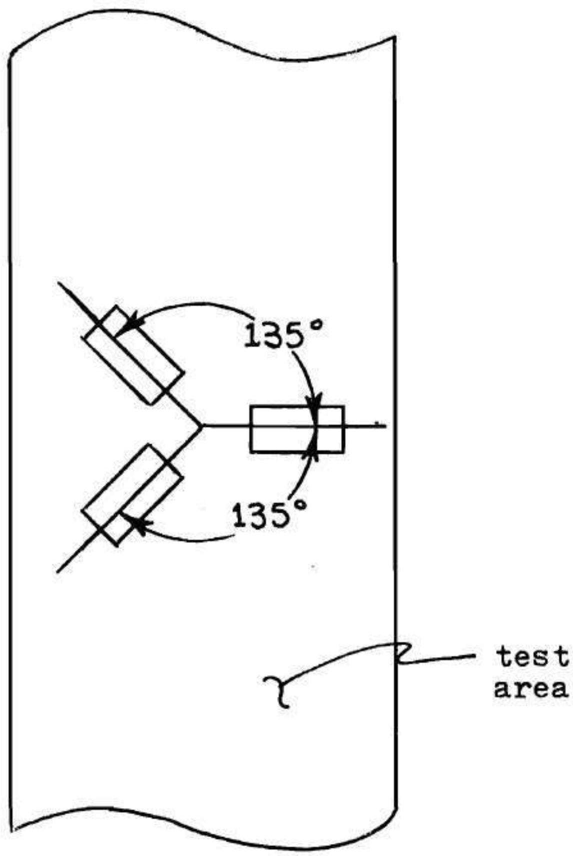

Figure 6. Strain Gage Orientation

the 3/8 inch diameter clamping bolt and the edge of the 1/2 inch diameter specimen hole was present. The means by which this can be accomplished may be left to the experimentor; however, the procedure used in these tests was to place the specimen on a single rail and visually maximize the clearance. The specimen was marked showing the exact rail location. The mating rail was then attached to the fixture and the alignment marks on the specimen were used to obtain proper bolt to hole clearance. After aligning the specimen, the bolts were inserted and lightly tightened to maintain the specimen in the proper location. The same procedure was then repeated with the remaining pair of rails.

When both sets of rails were affixed and the specimen properly aligned, the bolts were tightened to 50 ft-lbs torque. An initial test was performed using 30 ft-lbs of torque and slippage of the specimen occurred causing the bolts to bear against the edge of the specimen holes. Extensive crushing of the specimen hole edges and hole elongation resulted, accompanied by a greatly reduced ultimate strength value.

To rectify this condition, the rail clamping surface was lightly crosshatched with a metal scribe and the torque was increased to 50 ft-lbs. The additional friction induced by the crosshatching and the increased clamping force of the additional tightening of the bolts eliminated the slippage problem in further tests.

A definite order was used in tightening the clamping bolts to the prescribed 50 ft-lbs of torque. Starting with the bolt through the thickest section of the rail, the bolts were tightened in sequence moving up the rails. The sequence was repeated as the torque was applied in 10 ft-lbs increments until the 50 ft-lbs limit was achieved. Figure 7 shows the specimen mounted in the test fixture.

With the specimen mounted in the fixture, the Instron testing machine was zeroed and calibrated, and the load recorder pen was aligned with the chart paper. The strain gage lead wires were connected to the Budd Switching and Balancing Unit which was in turn connected to the Budd Strain Indicator. The strain indicating equipment was set to the proper gage factor (2.03) and half-bridge operation mode. Each arm of the strain gage rosette was balanced to produce a zero reading on the digital strain indicator. Figure 8 shows the strain reading equipment.

Having zeroed and balanced the equipment, the test was performed. The pen recorder was used to indicate the load value and examine load creep during the recording of strain gage output. Figure 9 shows a typical recorder plot. The strain readings were recorded at various load values to obtain strain data needed to compute shear modulus values. Strain readings were taken until the creep became too great or until the plastic range was obviously reached. After all strain readings were taken, the specimen was loaded to fail-

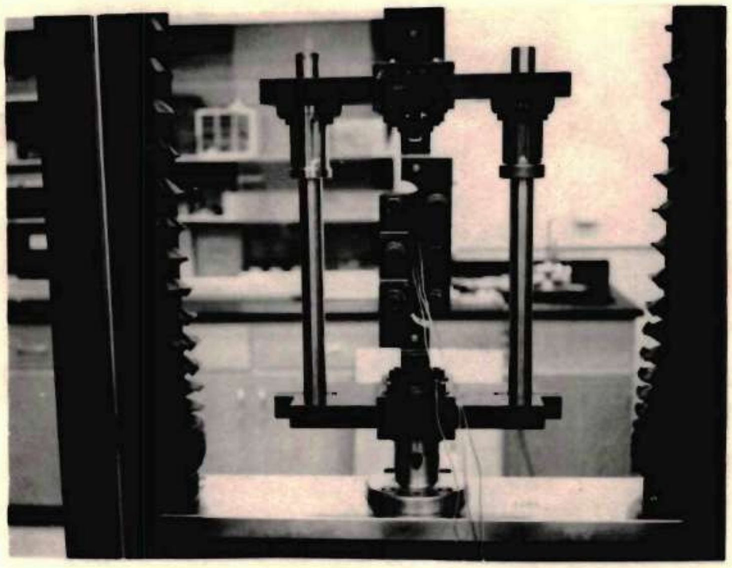

Figure 7. Test Fixture with Specimen

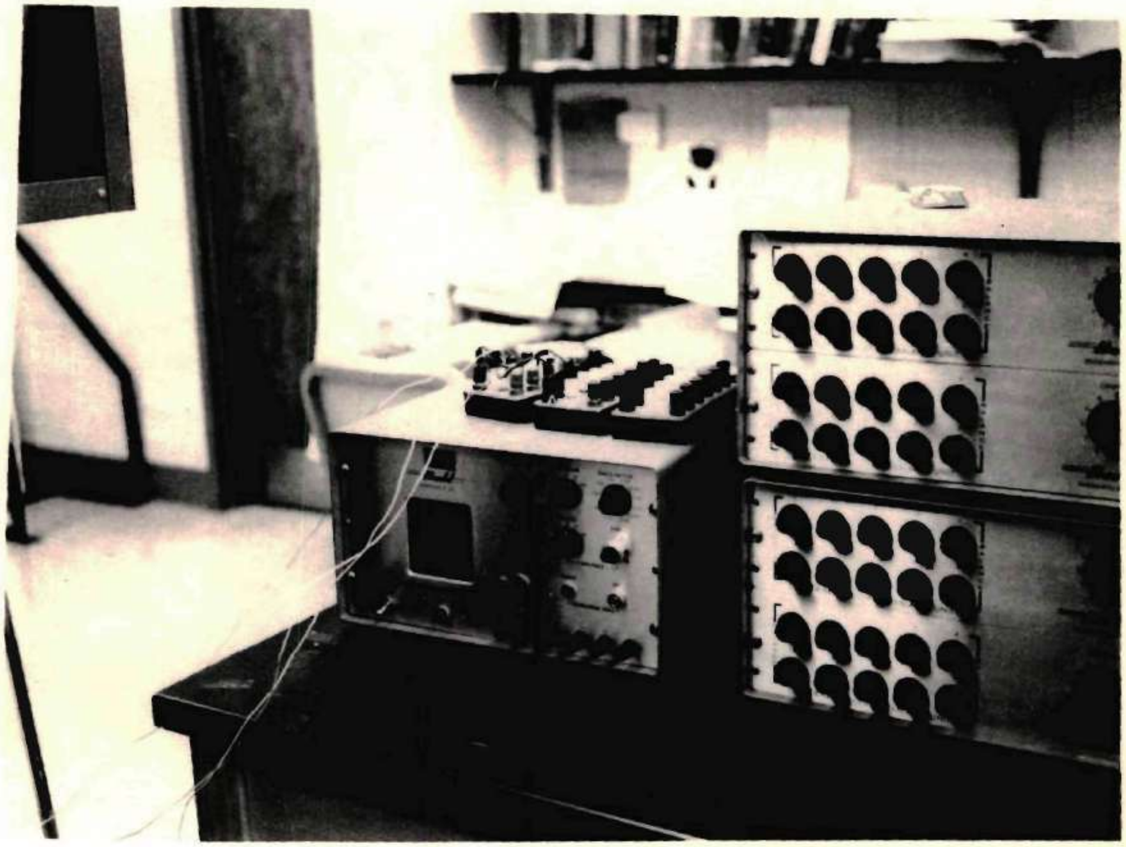

Figure 8. Strain Reading Equipment

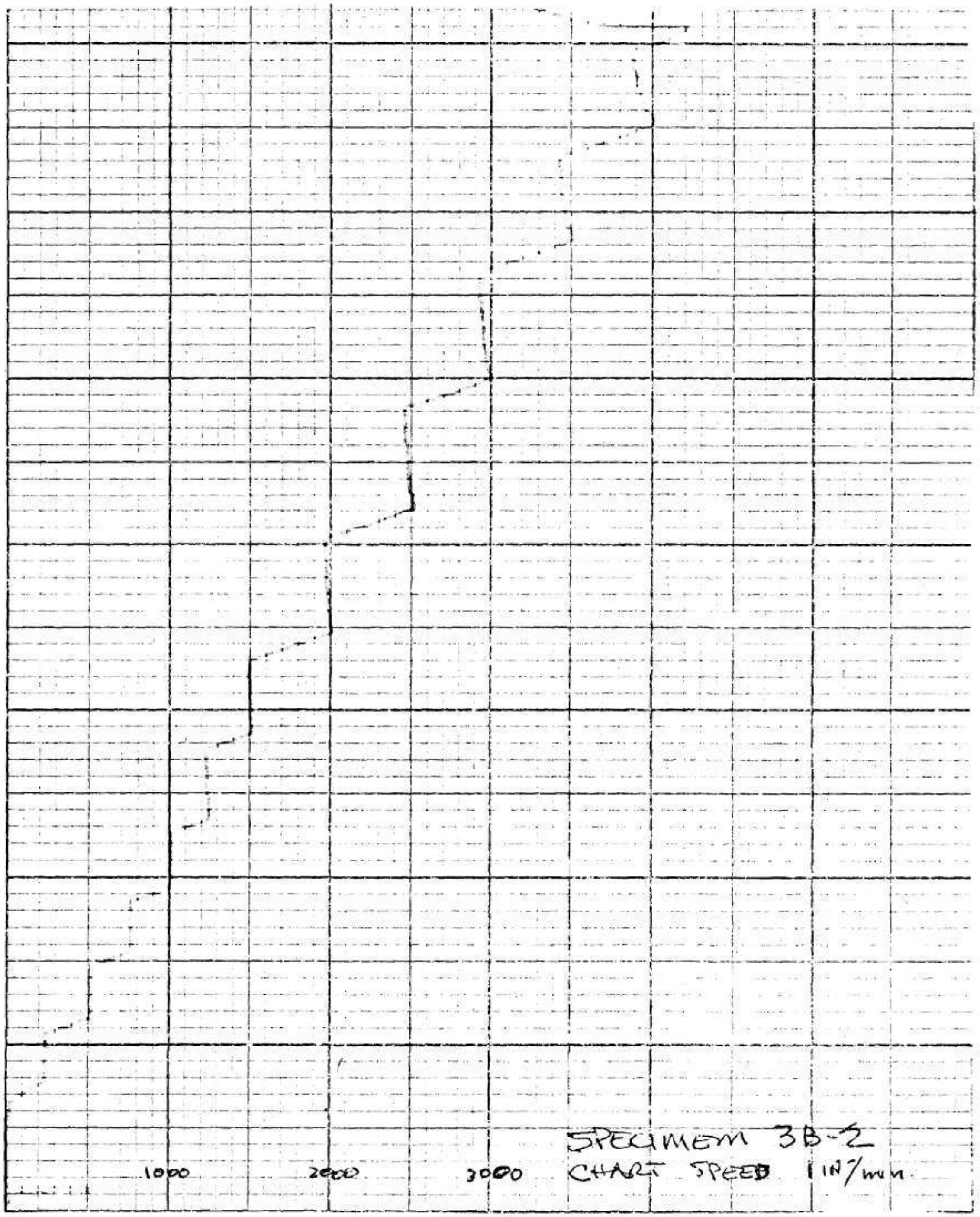

Figure 9. Typical Instron Recorder Plot

ure in all tests and the failure load recorded.

Test strain gage output and load values were then reduced to shear stress and shear strain values by a computer program. The computer program also computed the shear modulus values at the various load points.

During all tests, the Instron crosshead speed was set at 0.05 inches per minute and the chart speed of the Instron recorder at one inch per minute.

CHAPTER IV

EXPERIMENTAL RESULTS AND EVALUATION

A series of tests were performed using the modified rail shear test fixture, with the ultimate shear strength and the initial shear modulus being the properties to be determined for each group of laminate configurations.

The accuracy and worth of the test data was ascertained by comparison of the experimental results to shear strength and modulus values predicted by a computer laminate analysis program. The computer program (15) calculates the shear properties using the maximum strain criteria (16,17).

The results are presented for each major group separately and the overall test results are summarized at the end of the chapter. Within each group discussion the ultimate shear strength, initial shear modulus, failure description, and comparison to predicted values are reviewed individually.

Group 1 - 0/90 Laminates

Group 1 consisted of 16 specimens; eight specimens were of a symmetric lay-up (0/90/90/0) and eight were anti-symmetric (0/90/0/90) in configuration. All specimens were four ply (0.0208 inches) thick and conformed to the shape shown in Figure 1. Five specimens of each laminate configuration were instrumented using three arm strain gage rosettes.

Ultimate Shear Strength

The symmetric or 1A group gave very consistent shear strength values. The anti-symmetric configuration or 1B specimens exhibited slightly greater scatter but the average ultimate strength was within 0.15 per cent of the 1A specimens. The scatter, since it was small, could be attributed to the test procedure variance. Table 1 shows the strength values of each specimen.

Although Pagano and Pipes (18) indicate that stacking sequence can affect the ultimate strength of a laminate, no noticeable difference was observed between the symmetric and anti-symmetric laminates' failure strength. Since Pagano and Pipes used specimens of 12 to 18 plies, the stacking sequence effect may not be a factor in thinner laminates. Also, there was no apparent difference in the ultimate strength between the strain gaged specimens and those tested with no instrumentation.

Initial Shear Modulus

The initial shear modulus was calculated from the strain data obtained from the strain gage rosettes. A computer program was used to reduce this strain output. The modulus values were based on five specimens of each group and again the results of groups 1A and 1B were reasonably consistent. The stacking sequence had no significant effect on the shear modulus values. On the specimens of the anti-symmetric lay-up, strain gages were mounted on both the front and back

Table 1. Shear Strength and Modulus Values of 0/90 Laminates

Specimen	Ultimate Shear Strength (psi)	Initial Shear Modulus (x 10^6)
1A-1 *	12246	0.95
1A-2 *	12294	0.94
1A-3 *	12342	0.80
1A-4 *	12486	0.95
1A-5 *	11912	0.96
1A-6	12201	-
1A-7	12392	-
1A-8	12010	-
1A AVG	12236	0.94
1B-1 *	12438	0.97
1B-2 *	12916	1.00
1B-3 *	12294	1.00
1B-4 *	11625	0.97
1B-5 *	12103	0.98
1B-6	12105	-
1B-7	12342	-
1B-8	11912	-
1B AVG	12220	0.98
Total Avg	12228	0.96

* Strain gaged specimens

faces of the test area and the modulus values were unchanged from front to back. This procedure also served as a check for bending in the specimen test area. Since no modulus deviation was observed, the bending in the test area was considered negligible. Table 1 shows the modulus values of each specimen. A typical stress-strain curve is shown in Figure 10.

Failure Description

The failure pattern was identical for both groups 1A and 1B. The specimens did not experience complete failure, but failure was an extensive displacement of the rails relative to each other. As shown in Figure 11, the failure occurred in the center of the test area and followed a straight line path. It was a clearly evident shear failure. This test was expected to give this clear shear failure since the 0/90 degree filament material closely approximates an isotropic material. Some delamination was noted in most failures, especially on the zero degree plies. No buckling was observed in the test area during any of the tests.

Comparison to Predicted Results

The experimental results were compared to a set of predicted values generated by the laminate analysis computer program. Table 4 shows the comparison of the ultimate shear strength and initial shear modulus values. As seen, the experimental shear strength values are lower than those predicted. Although the test values are only approximately 70 per cent of the predicted values, they may be quite realistic.

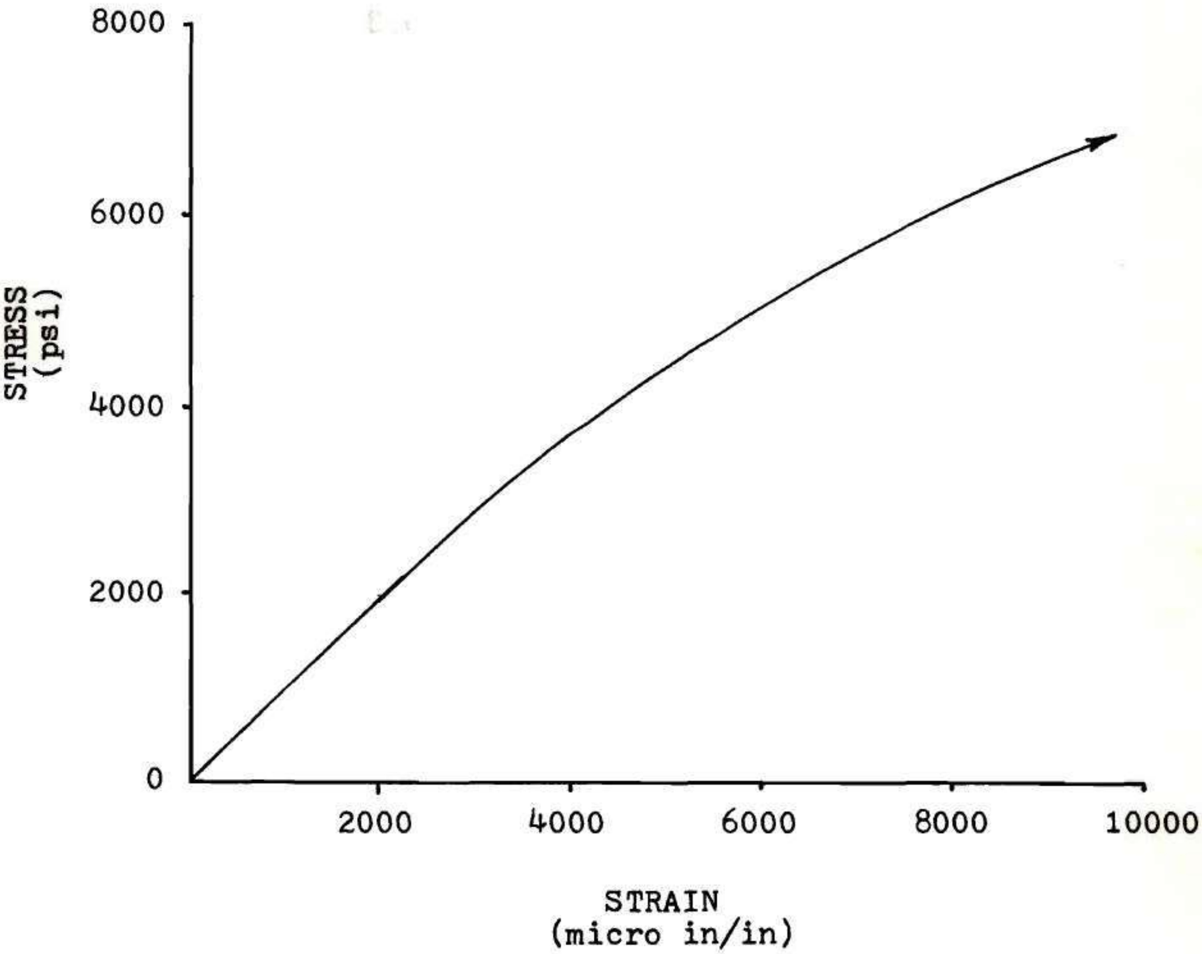

Figure 10. Stress-Strain Curve for 0/90 Laminates

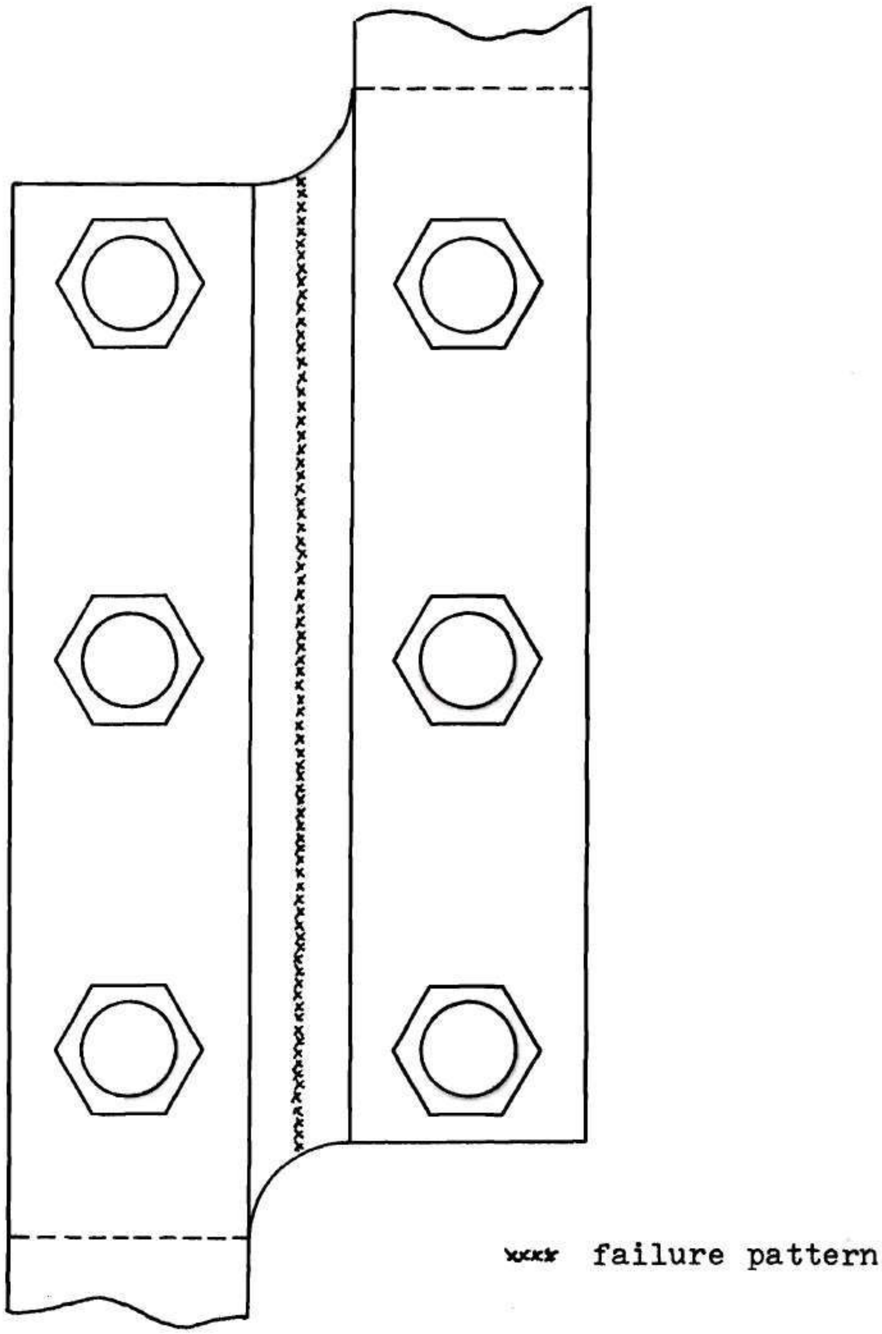

Figure 11. Failure Pattern for 0/90 Laminates

The predicted values may be slightly high; however, there is a lack of reliable shear strength data available to serve as a check.

Good agreement was found between the experimental and predicted shear modulus values. The experimental value was slightly higher than the predicted, but within the accepted variance of 5 per cent.

Group 2 - ±30 Laminates

Group 2 consisted of 16 specimens with a thickness of 0.0208 inches (four ply). Eight of the specimens were stacked symmetrically (+30/-30/-30/+30) and the remaining eight specimens were anti-symmetric (+30/-30/+30/-30) in configuration. Ten specimens, five of each configuration, had strain gage rosettes mounted in the center of the test area.

Ultimate Shear Strength

The strength values of groups 2A and 2B fell within an acceptable scatter range (5 to 8 per cent) with one notable exception. Specimen 2A-5 failed at 64,115 psi which was approximately 20,000 psi above the average. The reason was unknown but the value was considered to be so far from the norm as to be highly suspect. For this reason it was not included in the average. It should be mentioned, however, that its failure was typical of this group in pattern but much more destructive to the specimen. Table 2 shows the actual failure strength of the various other specimens. As is evident,

Table 2. Shear Strength and Modulus Values of ± 30 Laminates

Specimen	Ultimate Shear Strength (psi)	Initial Shear Modulus (x 10^6)
2A-1 *	42289	7.5
2A-2 *	41858	7.6
2A-3 *	39418	7.4
2A-4	45933	-
2A-5	64115	-
2A-6	52631	-
2A-7 *	37505	6.6
2A-8 *	44776	5.3
2A AVG	43493	7.0
2B-1 *	44202	6.6
2B-2 *	39514	7.3
2B-3 *	45733	6.5
2B-4 *	45063	6.7
2B-5 *	43054	6.5
2B-6	39234	-
2B-7	39235	-
2B-8	47847	-
2B AVG	42995	6.6
Total AVG	43224	6.8

* Strain gaged specimens

there was no appreciable difference between strength values in groups 2A and 2B. There was evidence, however that the specimens tested without strain gages did exhibit slightly higher strength values than the instrumented specimens. This was most likely due to weakening of the laminate by holding the load at various levels while strain output data was being recorded. As was indicated with the 0/90 degree laminates, the symmetric stacking sequence versus the anti-symmetric sequence had no apparent effect on the ultimate shear strength. The possibility of Pogano and Pipes' work not applying to thin laminates was again present.

Initial Shear Modulus

The initial shear modulus was computed from the strain gage rosette output with a computer program as in the 0/90 degree laminates. The modulus values, shown in Table 2, were within acceptable variance. The scatter might be attributed to the difficulty of aligning the small rosette in the extremely small test area. Specimens with gages mounted on the front and back of the test area showed no apparent bending in the specimen. As before, the stacking sequence of these laminates seemed to have a negligible effect on the modulus properties. A typical stress-strain curve is shown in Figure 12.

Failure Description

Both groups 2A and 2B exhibited the same failure pattern as shown in Figure 13. The failure generally initiated at a free edge and ran in a "saw-tooth" pattern through the

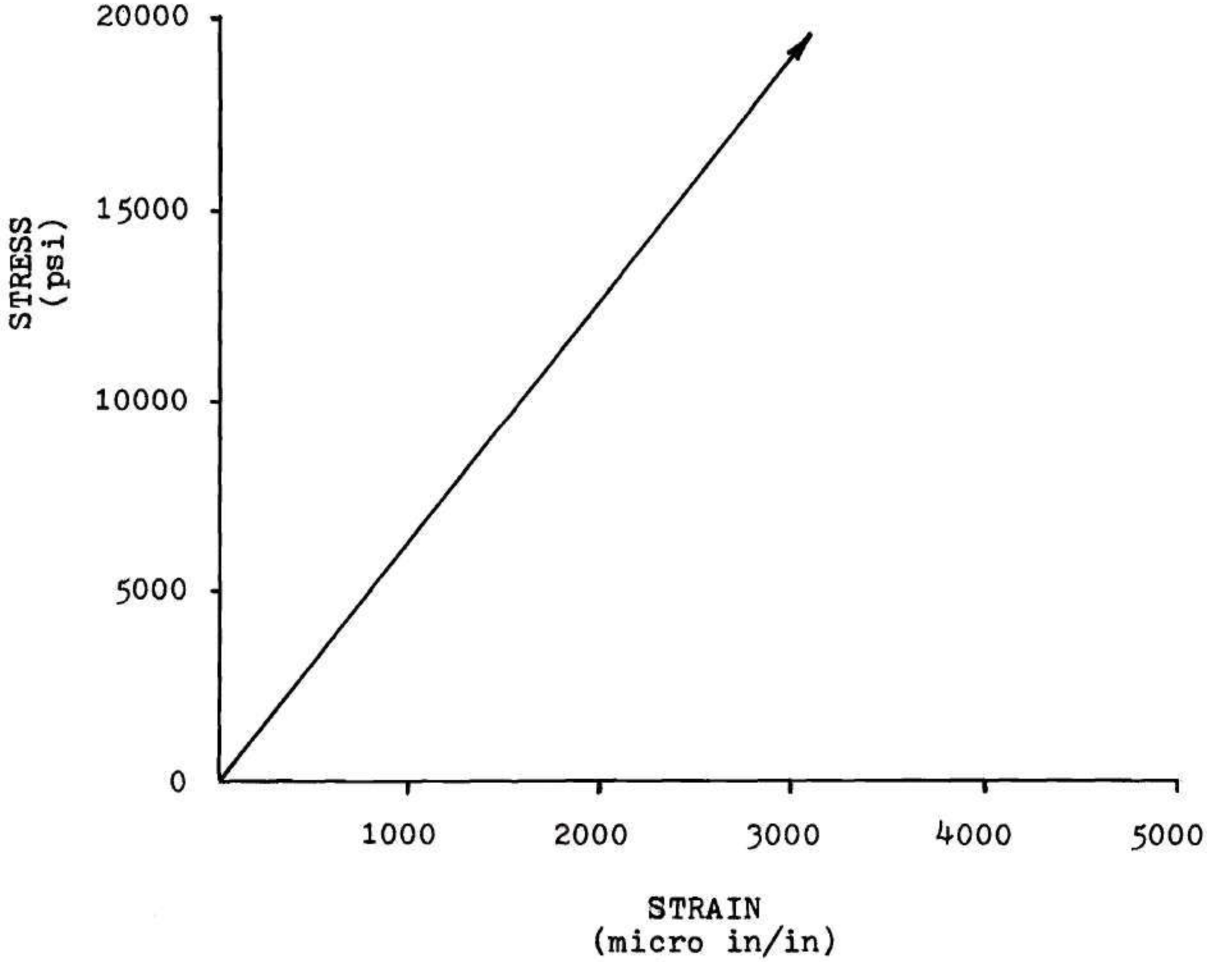

Figure 12. Stress-Strain Curve for ±30 Laminates

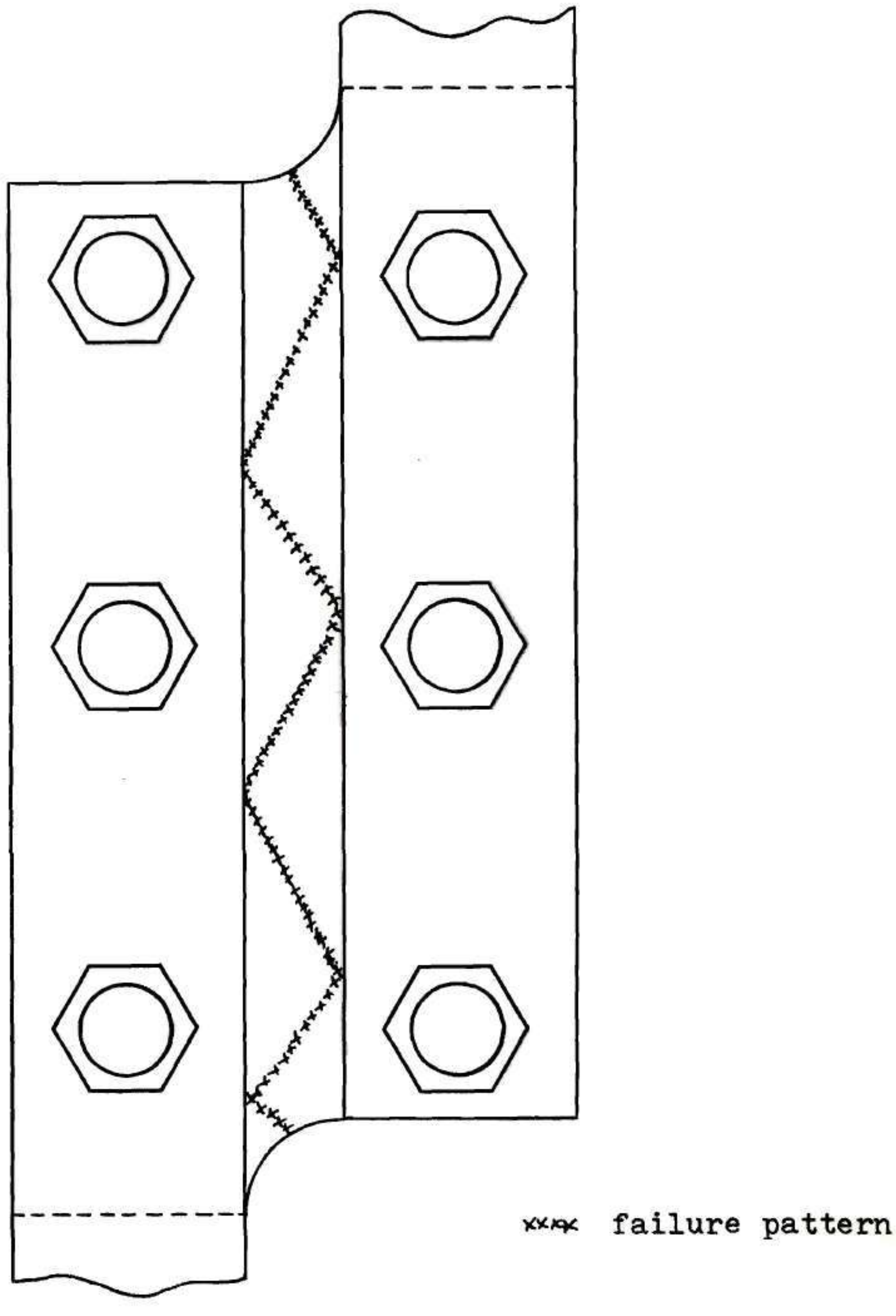

Figure 13. Failure Pattern for ± 30 Laminates

test area. There was some slight delamination in the center of the test area, but due to the catastrophic nature of the failure, it was impossible to determine at which point during failure the delamination occurred. The delamination was, however, believed to be due to shear. Reduction in the width of the test area, as a shear load was applied, probably induced the force needed to cause the visible delamination.

Comparison to Predicted Results

The shear properties determined from the test data were compared to the computer predicted results. This comparison is shown in Table 4. Experimental values of the laminate ultimate shear strength were approximately 82 per cent of the predicted values. These results present a strong case for the modified rail shear test since values obtained at Avco Aerostructures (19) using the picture frame fixture gave ultimate strength values of approximately 28,000 psi or 53 per cent of the predicted 53,000 psi.

Looking at the shear modulus values, the experimental results of group 2A were slightly higher than those predicted. The modulus values have, however, been calculated as high as 7.35×10^6, for this type of specimen, from the saddle deflection test (19). Once again gage orientation could be a factor in the scatter of the data. Group 2B values were more in line with the predicted values.

Group 3 - 0/±60 Laminates

Group 3 had one less specimen of each laminate configuration and consisted of six ply (0.0312 inches) thick specimens. Seven specimens were symmetric (0/+60/-60/-60/+60/0) in ply lay-up and seven were anti-symmetric (0/+60/-60/+60/-60/0) in construction. In both groups 3A and 3B, five specimens were chosen for instrumentation using strain gage rosettes. This left only two specimens in each group to be tested without instrumentation.

Ultimate Shear Strength

This series of specimens gave the greatest scatter in strength values of the three types of laminates tested. Table 3 shows the failure strengths of the group 3 test specimens. The data is considered good, however, because the maximum deviation from the average was less than 15 per cent. The scatter could possibly be explained by the fact that failure occurred at a very high load and any misalignment of the specimen would be magnified at such high loads. When looking at the stacking sequence of a specimen, the same conclusions reached in the other two groups still apply. The added thickness of two extra plies did not seem to be enough to subject this class of specimens to Pagano and Pipes' analysis of stacking sequence. Between the 3A and 3B specimens, there appeared no difference in the ultimate strength of the laminates.

Table 3. Shear Strength and Modulus Values of $0/\pm60$ Laminates

Specimen	Ultimate Shear Strength (psi)	Initial Shear Modulus (x 10^6)
3A-1 *	35081	4.3
3A-2 *	38334	4.7
3A-3 *	39036	4.6
3A-4 *	31509	4.8
3A-5 *	38844	4.9
3A-6	29660	-
3A-7	29600	-
3A AVG	34577	4.7
3B-1 *	26917	5.1
3B-2 *	35527	5.2
3B-3 *	32466	4.7
3B-4 *	36293	4.5
3B-5 *	38525	4.9
3B-6	32210	-
3B-7	31509	-
3B AVG	33359	4.9
Total AVG	33968	4.8

* Strain gaged specimens

Initial Shear Modulus

Shear modulus values obtained from the strain gage data was generated using a computer program with input from 10 specimens. Table 3 shows the modulus values for each individual specimen tested. The consistency of the modulus values of the 10 specimens was good and no deviation was observed between the strain data from the two sides of the test area. Group 3B did have a higher average shear modulus value than group 3A, but this was felt to be due to test data scatter rather than any stacking sequence effect. A typical stress-strain curve for this laminate configuration is shown in Figure 14.

Failure Description

Once again the failure pattern was identical for the symmetric and anti-symmetric laminates. In this laminate configuration, the failure was extremely catastrophic and extensive destruction of the laminate in the test area was observed. Figure 15 shows the irregular "saw-tooth" pattern that the failure normally exhibited. The pattern was more irregular than that experienced in the ± 30 degree laminates. It closely resembled the failure pattern reported in Gruman's Quarterly Report of May 1969 (20). The failure occurred so rapidly that its origin was impossible to identify. It was noted, however, that extensive delamination was observed in the center of the test area. If the specimen was not evenly loaded, possibly due to misalignment, the failure pattern de-

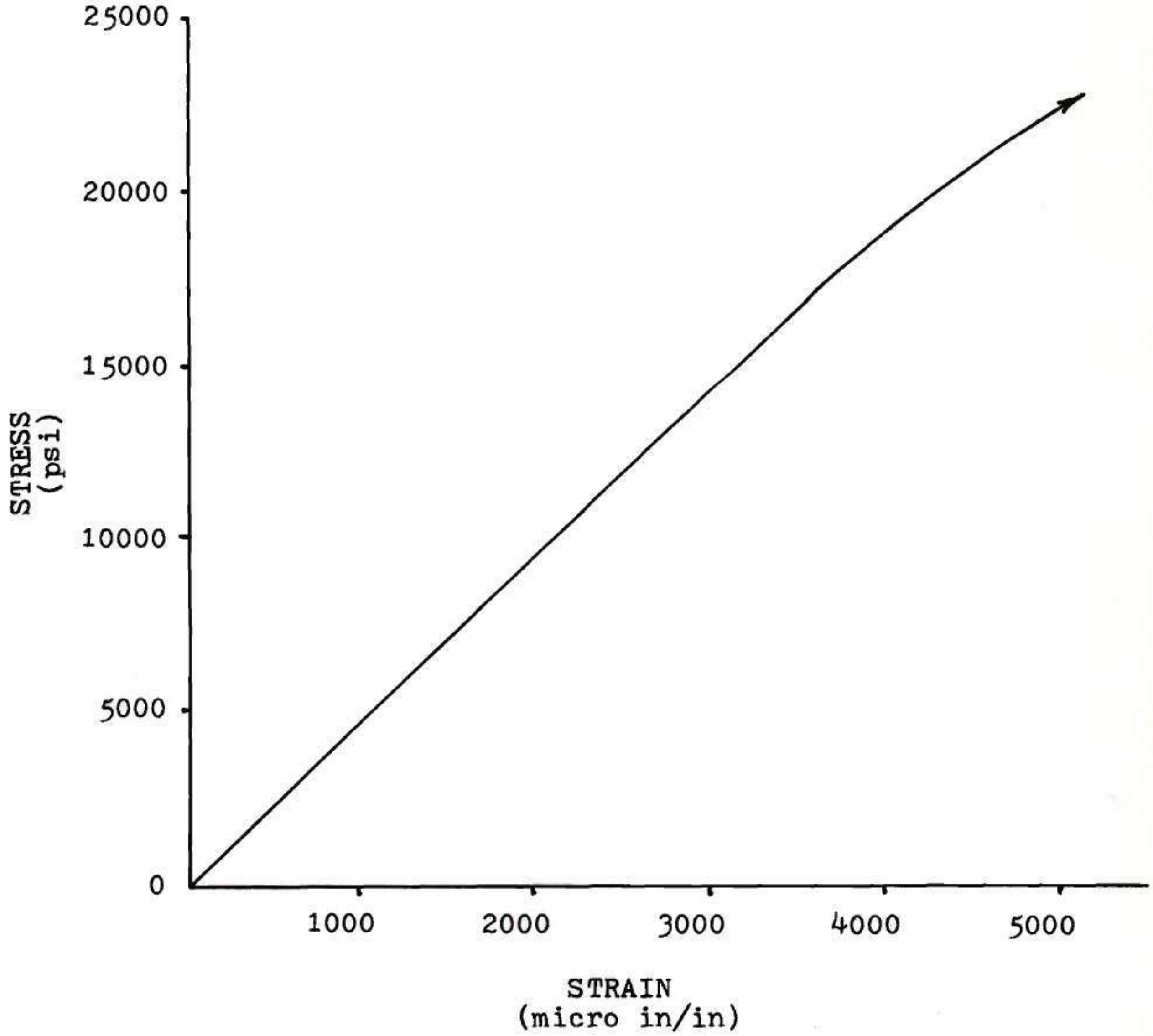

Figure 14. Stress-Strain Curve for 0/$\pm$60 Laminates

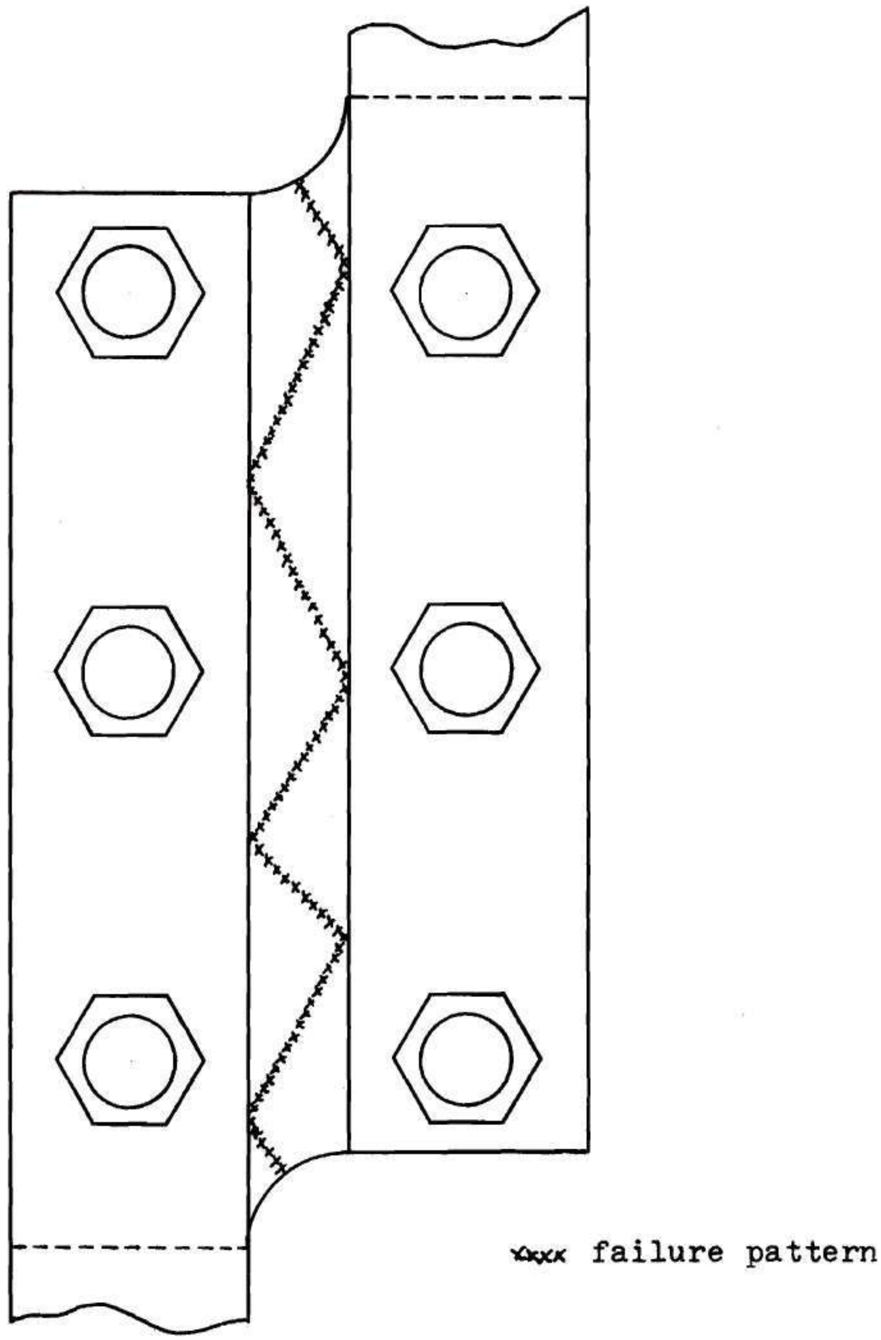

Figure 15. Failure Pattern for 0/$\pm$60 Laminates

scribed above does not occur. Instead, the specimen will fail at one corner with the crack pattern running through a hole. This type of failure was experienced by specimen 3B-1 and the strength value was lower than the other specimens. This points out the sensitivity of failure to the test procedure.

Comparison to Predicted Results

The shear properties of group 3 laminates produced the most favorable comparison to the predicted results of any of the groups tested. Table 4 shows the excellent agreement of both ultimate shear strength and initial shear modulus values to the predicted results. Experimental shear strength values represent approximately 92 per cent of the expected strength values. Isolated specimens such as 3A-2, 3A-3, 3A-5, and 3B-5 even exceeded the predicted strength of 37,000 psi. Upon examination of the shear modulus data, the experimental results indicate a slightly higher modulus value for group 3B. The higher average of this group is primarily due to specimens 3B-1 and 3B-2. A slight misorientation of the strain gage is a probable reason for these high values. All other specimens give modulus values near the predicted results. This group of tests gave good creditation to the modified rail shear test.

Overall Evaluation of the Test

In evaluating the modified rail shear test, one should observe that the results obtained represent the clearest picture. As Table 4 shows, the test results compare quite favorably to the laminate analysis predicted results. Since there is, at present, no reliable experimental data on the shear properties of this composite material, the analysis program results offer the only acceptable standard. Although these predicted values may be slightly in error, the modified rail shear test supports them experimentally; however, from the other view point, the predicted values indicate the test is reasonably accurate.

The modified rail shear test gave both repeatable ultimate shear strength and initial shear modulus from a single test. The test data scatter was within an acceptable range and could in all probability be reduced with certain refinements of the test. Test results also show that thin laminates can be used and meaningful results are produced. In addition, the series of tests indicate that specimens of different filament orientations give good results.

From an overall view, the modified rail shear test results strongly indicate that the test possesses a great deal of merit, and the experimental shear properties obtained from it are repeatable.

Table 4. Comparison of Experimental Results to Predicted Values

Specimen	Experimental Shear Strength (psi)	Predicted Shear Strength (psi)	Experimental Shear Modulus (x 10^6)	Predicted Shear Modulus (x 10^6)
1A	12236	18000	0.94	0.9
1B	12220	18000	0.98	0.9
AVG	12228	18000	0.96	0.9
2A	43493	53000	7.00	6.5
2B	42995	53000	6.60	6.5
AVG	43224	53000	6.80	6.5
3A	34577	37000	4.70	4.6
3B	33359	37000	4.90	4.6
AVG	33968	37000	4.80	4.6

CHAPTER V

CONCLUSIONS

A modified rail shear test fixture was designed and built. The test fixture was designed for use in an Instron Universal Testing Machine, but could easily be adapted to other types of universal testing equipment. It used a convenient size specimen; therefore, the test could be performed at various test temperatures. The test fixture allowed for strain gage application to measure strain values in the test area.

A series of tests were performed using this fixture to determine the shear properties of thin composite plates. The tests were performed on three groups of boron filament composite specimens — 0/90, ±30, and 0/±60 ply configurations.

The 0/90 degree laminate specimens were four ply thick with half the group being symmetric (0/90/90/0) in ply lay-up and the remaining half anti-symmetric (0/90/0/90) in configuration. The ultimate shear strength value for these laminates was lower than the value predicted by a computer laminate analysis program. The modulus values were, however, in good agreement with predicted results. Failure in these specimens was of an obvious shear nature through the center of the test section. Stacking sequence produced no apparent effect on either shear strength or shear modulus.

The ±30 degree laminates also consisted of the symmetric (+30/-30/-30/+30) and anti-symmetric (+30/-30/-30/+30) configurations and of four ply thickness. Ultimate shear strength values were approximately 82 per cent of those predicted and initial shear modulus were repeatable. The failure crack pattern ran in a definite "saw-tooth" fashion through the test area. Shear delamination was present in a majority of the specimens. Once again the symmetric versus the anti-symmetric ply stacking had a negligible effect on both the strength and modulus values.

The final group of laminates was the 0/±60 degree specimens. This group followed the same format of symmetric (0/+60/-60/-60/+60/0) and anti-symmetric (0/+60/-60/+60/-60/0) ply configurations; however, these specimens were six ply thick. This group of specimens gave excellent results. The ultimate shear strength values were approximately 92 per cent of the predicted values with four specimens even slightly exceeding the predicted failure strength. The modulus values also were good and in excellent agreement with the predicted results. Failure in these specimens was catastrophic with the fracture following an irregular "saw-tooth" pattern. Destruction of the test area was extensive with severe delamination occurring in the center of the test area. The six ply thickness seemed to remain in the thin laminate range with no stacking sequence effect observed in either strength or modulus values.

In general, the test results were acceptable and repeatable. The buckling problem encountered by previous rail shear testing was apparently alleviated, since no buckling was observed in the test area during any of the tests. The results indicate that this modified rail shear test provides an excellent method of obtaining both ultimate shear strength and initial shear modulus from a single test.

CHAPTER VI

RECOMMENDATIONS

Fixture Redesign

The problem of applying the load evenly to the specimen was the most difficult one encountered. In this area, the difficulties in aligning the specimen, insuring hole clearance, and even clamping along the rails might all be solved by a redesign of the clamping fixture.

A possible solution would start with the removal of the holes in the specimen. Instead of clamping the rails using bolts, a load tab of some load transferring material should be bonded to the specimen. The material used could be fiberglass or some similar material. Various possibilities could be found from data on load tabs used in tension testing of composite materials (21). The load tab would cover the area which the rail normally contacts on the specimen.

The rails' inner surface should be serrated with the teeth angled toward the direction of movement of the set of rails. A tightening or gripping mechanism would clamp the rails to the load tabs. A mechanism similar to the one used on the standard 20,000 pound Instron 10F Wedge Action grips could be designed. These grips consist of grip faces which use the special flat 25 teeth-per-inch diamond serration type, and are adjustable to open from zero to one-fourth inch. The grips are tightened onto a sample without altering the vertical position of the faces. This precludes any initial buckling of the specimen while loading in the grips. The grips operate on an ever increasing wedging principle which allows the grips to maintain the force on the specimen even under high loads. After rupture, the grips exhibit no recoil. The serration would prevent slippage and yet not damage the specimen.

The bonded load tabs would improve load distribution, would ease the problems of alignment, and would protect the specimen from the serration of the rails. In addition, the use of load tabs enables the removal of the holes in the specimen. This relieves any stress concentrations inherent with the presence of holes. Fabrication of the specimen would also be made easier.

Further Studies

A large number of promising future studies using this modified rail shear test are present. A similar study to the one presented in this thesis with specimens of cross ply orientation at various intervals, i.e. ±15, ±30, ±45, ±60, and ±75, might lead to important design information of ply orientation related to shear strength.

Another aspect to investigate would be the effect of thickness on laminate properties. Using one filament orientation and varying the number of plies would be a means to examine the effect of thickness on the laminate.

The diminished buckling problem also suggests the possibility of increasing the test area and relaxing the width to length ratio. This should bring the specimen test area in closer agreement with St. Venant's principle.

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